The Majorana Project: A Next-Generation Neutrino Mass Probe

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Outline

- Introduction and Overview
- Reference Concept
  - Configuration
  - Materials
- Backgrounds and Mitigation
  - Pulse-Shape Discrimination
  - Detector Segmentation
- Experiment Sensitivity
- Progress and Status
- Conclusions
**Majorana Overview**

**GOAL:** Sensitive to effective Majorana mass near 50 meV

$0^+\gamma\beta$ decay of $^{76}\text{Ge}$ potentially measured at 2039 keV

Based on well known $^{76}\text{Ge}$ detector technology plus:
- Pulse-shape analysis
- Detector segmentation

**Requires:**
- Deep underground location
- 500 kg enriched 86% $^{76}\text{Ge}$
- many crystals, segmentation
- Pulse shape discrimination
- Time/Spatial Correlation
- Special low-background materials

Reference Configuration
Detector Configuration

- Granularity, low passive mass, are goals
- Optimization underway of performance and risk
  - Several low-risk designs possible for modular cryostats
  - Many segmentation schemes possible and equally effective
  - Nature of Ge crystals allows repackaging
Low-Background
Electroformed Copper

- Can be easily formed into thin, low-mass parts
- Recent designs reduce $m_{\text{Cu}}/m_{\text{Ge}} \times 5$
- UG Electroforming can reduce cosmogenics
- Pre-processing can reduce U-Th
- Recent results suggest cleaner than thought

Electroformed cups shown have wall thickness of only 250 µm!
Starting Background Estimate

International Germanium Experiment (IGEX) achieved between 0.1-0.3 counts/keV/kg/y

Documented experiences with cosmic secondary neutron production of isotopes

<table>
<thead>
<tr>
<th>Spallation Isotope</th>
<th>$T_{1/2}$ (d)</th>
<th>Rate from [Bro95]</th>
<th>After Construction</th>
<th>Rate During Experiment</th>
<th>Total in ROI</th>
<th>After PSD Rejection</th>
<th>After Seg Rejection</th>
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<td>$^{68}$Ge</td>
<td>270.82</td>
<td>0.1562</td>
<td>0.03702</td>
<td>3.93E-03</td>
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<td>0.0177</td>
<td>0.01294</td>
<td>7.15E-03</td>
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<td>cts/keV/kg/y</td>
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<td>0.0523</td>
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<td>198.95</td>
<td>52.72</td>
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Segmentation & Pulse-Shape Discrimination

- Allow rejection of multiple-site interactions
- Effective against projected backgrounds
- Granularity Costs Money/Should be optimized

Different Schemes Being Evaluated
- Segmented Large N-type Crystals
- Multiple Small P-type Crystals
- Segmented Large P-type Crystals
Why Now is a good time for PSD….

- Commercial digital spectroscopy hardware is available with fast (40 MHz), high-resolution (14-bit) digitization
- Significant developments in pulse-shape discrimination techniques for HPGe have been made in the past 10 years and are ready to apply to new hardware

Full-energy 1621-keV (top) and 1592-keV DEP (bottom) reconstructed current pulses from 120% P-type Ortec HPGe detector (experimental data)
PSD can reject multiple-site backgrounds (like $^{68}$Ge and $^{60}$Co)

- $^{228}$Ac 1587.9 keV
- DEP of $^{208}$Tl 1592.5 keV
- $^{212}$Bi 1620.6 keV

Experimental Data

- Original spectrum
- Scaled PSD result
- Keeps 80% of the single-site DEP (double escape peak)
- Rejects 74% of the multi-site backgrounds (use $^{212}$Bi peak as conservative indicator)
- Improves $T_{1/2}$ limit by 56%
Detector Segmentation

- Sensitive to axial and azimuthal separation of depositions
- Example design with six azimuthal and two axial contacts in a 2-kg detector
- This segmentation gives ~2500 segments of 200 g (or 40 cm$^3$) each
- Many segmentation schemes give equivalent good background rejection
Monte-Carlo Example
(single crystal)

Internal $^{60}$Co before and after one-segment cut

Sensitive to $z$ and phi separation of depositions

- $\phi$ efficiency = 91%
- Internal $^{60}$Co efficiency = 14%
- Improves $T_{1/2}$ limit by 140%

Next Steps:
- $T$ improvement increases to 260% - 620% when including array self-shielding, depending on position of crystal – not included in earlier background estimate
- Time-series analysis of background very promising

Segment multiplicity at 2039 keV
Sensitivity vs. Time

- **Slow Production**: Gradual ramp to 100 kg/y - total 500 kg 85% $^{76}$Ge
- **Fast Production**: 200 kg/y (No ramp)
- Present $^{76}$Ge $T_{1/2}$ limit rapidly surpassed ($T_{1/2} > 1.9 \times 10^{25}$ y)

Based on early IGEX background levels with reasonable background reduction and cutting methods applied
Collaboration Progress:
Optimizations for Full Experiment

Segmented Enriched Germanium Array (SEGA):
Segmented Ge
1 to 5 Crystals
First enriched, segmented detector in testing!
Additional tests being planned for other segmented systems

Multi Element Germanium Assay (MEGA):
16+2 natural Ge

High density
Materials qualification
Cryogenic design test
Geometry & signal routing test
Powerful screening tool

MAJORANA:
500 kg Ge detectors
All enriched/segmented Multi-crystal modules

Full Experiment
Progress and Status
SEGA: Segmentation Optimization

First (enriched) 6x2 SEGA operating
- Current: Testing (TUNL)
- Shallow UG testing at U Chicago LASR facility
- Operation in WIPP

Second and third SEGA planning
- Funds in hand (LANL, USC)
- Alternate segmentation testing underway (USC/PNNL)
- 40-fold-segmented LLNL detector now available

Figure-Of-Merit vs. Axial & Azimuthal Segmentation for internal $^{60}$Co background

SEGA crystal initial test cryostat
Progress and Status

Ultra-Low Level Screening

Screening facility
- Operating in Soudan (Brown U)
- Two HPGE detectors (1.05 kg, 0.7 kg)

Planned use for screening
- Minor materials used in manufacturing
- Improved Cu testing
- Small parts qualification
  - FET, cable, interconnects, etc
Progress and Status
MEGA: Cryogenic testing

- Materials in hand
  - Detectors (20 - 70% HPGe), electronics
- Assembly and cryogenic testing of two-crystal modules underway (PNNL, UW, NC State)
- Underground facility (WIPP) in prep (LANL, NMSU)
- Fall 2003 installation anticipated
- Sensitive to $\sim 10^4$ short-lived atoms
MEGA Infrastructure at WIPP

- Steel sub-floor to support many-ton lead shields
- Cleanroom enclosure with antechamber entry
- Power, network connectivity

Q-Room Alcove
Module Assembly & Testing

(MEGA)
Conclusions

Reference Plan meets sensitivity goals
- Opportunities for enhancements exist
- Potential for discovery

Unprecedented confluence:
- Enrichment availability/Neutrino mass interest/
  Underground facility development

High Density:
- Modest apparatus footprint, no special cavity required

Low Risk:
- Proven technology/ Modular instrument / Relocatable
- Early results / Incremental deployment

Experienced and Growing Collaboration
- Long track record, many technical resources